


Original Research

Isometric Knee Strength is Greater in Individuals Who Score Higher on Psychological Readiness to Return to Sport After Primary Anterior Cruciate Ligament Reconstruction

Barrie S. Sugarman¹ ^a, Zach B. Sullivan², Daniel Le³, Carolyn Killelea⁴, Mallory S. Faherty⁵, Lee H. Diehl⁴, Jocelyn R Wittstein⁴, Jonathan C. Riboh⁶, Alison P. Toth⁴, Annunziato Amendola⁴, Dean C. Taylor⁴, Timothy C. Sell⁷

¹ Orthopaedic Surgery, University of Michigan, ² Radiology, Boston Medical Center, ³ School of Medicine, University of North Carolina, ⁴ Orthopaedic Surgery, Duke University Medical Center, ⁵ Ohio Health Research Institute, ⁶ OrthoCarolina, ⁷ Atrium Health Musculoskeletal Institute

Keywords: anterior cruciate ligament reconstruction, psychological readiness, return to sport

<https://doi.org/10.26603/001c.39737>

International Journal of Sports Physical Therapy

Vol. 17, Issue 7, 2022

Background

Anterior cruciate ligament (ACL) injury is extremely common among athletes. Rate of second ACL injury due to surgical graft rupture or contralateral limb ACL injury is approximately 15-32%. Psychological readiness to return to sport (RTS) may be an important predictor of successful RTS outcomes. Psychological readiness can be quantified using the ACL Return to Sport after Injury (ACL-RSI) questionnaire, with higher scores demonstrating greater psychological readiness.

Purpose

The purpose of this study was to investigate differences in functional performance and psychological readiness to return to sport among athletes who have undergone primary ACL reconstruction (ACLR).

Study Design

Descriptive cohort study

Methods

Eighteen athletes who had undergone primary ACLR were tested at time of RTS clearance. The cohort was divided into two groups, high score (HS) and low score (LS), based on median ACL-RSI score, and performance on static and dynamic postural stability testing, lower extremity isokinetic and isometric strength testing, and single leg hop testing was compared between the groups using an independent samples t-test.

Results

The median ACL-RSI score was 74.17. The average ACL-RSI score was 83.1±6.2 for the HS group and 61.8±8.0 for the LS group. High scorers on the ACL-RSI performed significantly better on isometric knee flexion as measured via handheld dynamometry (22.61% ±6.01 vs. 12.12% ±4.88, p=0.001) than the low score group.

^a Corresponding Author

Barrie S. Sugarman
University of Michigan Department of Orthopaedic Surgery
Attn: Sheila Menna
1500 E Medical Center Drive
TC2912, SPC5328
Ann Arbor, MI 48109
sugarmab@med.umich.edu

Conclusion

The findings suggest that increased knee flexion strength may be important for psychological readiness to RTS after primary ACLR. Further research is indicated to explore this relationship, however, a continued emphasis on improving hamstring strength may be appropriate during rehabilitation following ACLR to positively impact psychological readiness for RTS.

Level of Evidence

III

INTRODUCTION

Anterior cruciate ligament (ACL) injury is common among athletes.^{1,2} Rate of second injury due to surgical graft rupture or contralateral limb injury is approximately 15-32%, with increased risk during the first two years postoperatively.³⁻⁷ Known factors associated with successful return to sport (RTS) include delay of return until at least nine months postoperatively, symmetric quadriceps strength measured as a ratio of knee extensor torque normalized to body mass, lower levels of pain and knee joint effusion, lower levels of kinesiophobia, and extended preoperative rehabilitation.^{4,6,8-10} Successful return to sport is primarily defined as avoidance of second injury, but can also include return to pre-injury activity levels or avoidance of pain with activity. Despite the identification of these predictors, ACL reinjury rates remain high, suggesting that other factors may play an important role in successful RTS. One of these additional factors may be psychological readiness to RTS, which includes fear of reinjury, anxiety, anger, and stress, and lack of confidence to return to sport.¹¹ Approximately 40-63% of athletes return to their preinjury level of sport after primary ACL injury,¹²⁻¹⁴ and among athletes who do not return, fear of injury is the most common reason they cite for this decision.¹⁵ Lack of psychological readiness is a major barrier for return to preinjury level of sport after ACL reconstruction (ACLR).^{13,16-18} Psychological factors, in addition to physical readiness, are important to consider in RTS evaluation.^{8,11,15}

Several authors have indicated that psychological readiness predicts successful RTS.^{13,14,19-23} Psychological readiness to return to sport may be quantified using a questionnaire known as the ACL Return to Sport after Injury (ACL-RSI) scale.²⁴ Webster et al. developed this 12-item questionnaire in 2008 to assess the psychological impact of returning to sport after ACLR.^{10,24} The scale measures psychological readiness to RTS after an ACL injury in three main categories: emotions, confidence, and risk appraisal, and a higher score suggests greater psychological readiness for return to sport.^{21,24,25} The ACL-RSI has been shown to be a good indicator of successful RTS.^{10,11,23} Sadeqi et al. describes that ACL-RSI score improves throughout the rehabilitation process, and that higher ACL-RSI score is correlated with an athlete's return to sport.²⁵ Athletes who return to sport after ACLR have higher ACL-RSI scores than athletes who do not return to their sport even after being medically cleared to do so.^{10,15} Importantly, young athletes (<20 years of age) who sustain a second ACL injury after RTS had lower psychological readiness scores at 12 months af-

ter ACLR and a smaller change in their ACL-RSI score from preoperative evaluation to 12 months postoperative evaluation than their counterparts who do not sustain a second injury.^{21,22} ACL-RSI score indicates psychological readiness for successful RTS, and therefore may be a useful tool in RTS evaluations for athletes.

Although there is strong evidence demonstrating that psychological readiness plays a significant role in successful RTS, the predictors of psychological readiness remain largely unknown. The purpose of this study was to investigate differences in functional performance and psychological readiness to return to sport among athletes who have undergone primary ACLR. Predictors of high ACL-RSI scores will be determined based on single leg functional performance in single leg hop for distance, quadriceps strength testing, and single leg static postural stability and Dynamic Postural Stability Index (DPSI). Because athletes with higher ACL-RSI scores are shown to have greater success in RTS, it was hypothesized that subjects in this study with higher ACL-RSI scores will perform better in functional testing at time of RTS than athletes with lower ACL-RSI scores. Findings from this study may guide clinicians when determining how psychological factors contribute to functional performance. These results may also affect both physical and psychological rehabilitation for athletes after ACLR to improve RTS outcomes.

METHODS

STUDY DESIGN AND PARTICIPANTS

This descriptive cohort study utilized individuals who had undergone a primary ACLR at a single academic institution. Subjects were recruited to participate if they were 12 years or older and had undergone primary ACL reconstruction with a contributing author orthopaedic surgeon. A total of 18 participants enrolled in the study voluntarily. All subjects were cleared by their orthopaedic surgeon to return to their previous level of activity prior to participation in the study.

Subjects were included in this study if they participated in a sport at any level prior to their injury, and intended to return back to sport after being cleared to do so. Subjects were excluded if they had a history of any prior major lower extremity injuries, prior lower extremity or back surgery, any medical diagnosis that could affect balance, or any multi-ligamentous injury. Concurrent meniscal injury was not an exclusion criterion. Subject demographics for the co-

Table 1. Participant demographics

	Age (years) Range: 13-36		Height (cm)		Mass (kg)		Tegner Activity Level	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
Females (n=8)	19.4	5.73	165.88	7.38	76.33	25.82	6.75	1.58
Males (n=10)	20.8	7.04	178.97	8.02	76.89	10.74	7.70	1.25
Total (n=18)	20.2	6.35	173.15	10.06	76.64	18.32	7.28	1.44

hort are outlined in [Table 1](#). All subjects read and signed an informed consent form prior to participating in the study.

INSTRUMENTATION

Ground reaction forces (GRF) for static and dynamic postural stability testing were collected at 1000 Hz with an AMTI force plate (Advanced Mechanical Technologies, Inc., Watertown, MA, model BP600900). Knee isokinetic strength was measured using an isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY), and knee isometric strength was measured using a handheld dynamometer (Lafayette Instrument Company, Lafayette, IN).

PROCEDURES

Participants completed the ACL Return to Sport after Injury (ACL-RSI) 12-item questionnaire at time of RTS clearance, as previously described. Several studies have used the ACL-RSI, and the questionnaire shows high internal consistency (Cronbach alpha = 0.96).^{14,15,20,21,23,26-28}

Subjects also completed the Tegner Activity Scale prior to functional performance testing. The Tegner Activity Scale is a scored assessment from zero to ten that assesses the activity level in daily life and sport or recreation that a participant can comfortably complete.²⁹⁻³¹ Participants may only achieve a score of five or greater if they participate in recreational or competitive sports.²⁹ The activity scale has been shown to have high test-retest reliability.^{29,31} Average Tegner Activity Level for the cohort at time of RTS testing is reported in [Table 1](#).

Static postural stability testing was assessed under eyes open (EO) and eyes closed (EC) conditions. Participants assumed a single-leg stance on their injured leg on the force plate with their hands on their hips and were asked to focus on a marker at eye level approximately ten feet in front of them for a total of ten seconds in EO condition. Subjects assumed the same stance with their eyes closed for EC condition. Subjects completed one practice trial for each condition before three ten second trials were collected for data analysis. Trials were repeated if the subject shifted their standing foot on the force plate or touched down with their opposite foot off of the force plate. This protocol has been previously described and found to have excellent inter-session reliability.³²⁻³⁷ The standard deviation of the GRF were calculated for each trial in the anterior-posterior, medial-lateral, and vertical directions. In addition, an overall composite GRF was calculated for each trial. These val-

ues were averaged across the three trials for the eyes open and eyes closed conditions following data reduction.

For dynamic postural stability testing, participants were instructed to jump forward from a two-legged stance over a 30.5 cm hurdle to a force plate that was positioned at a distance of 40% of their height. Subjects were asked to land on their injured leg on the force plate and hold the stance for at least five seconds after landing. Trials were discarded if the subject did not land with one foot entirely on the force plate or if they were unable to hold a single leg stance after landing for at least five seconds. This procedure has been previously described in the literature and has good inter-session reliability.^{8,35-39} The dynamic postural stability index (DPSI) for each GRF component was calculated for the anterior-posterior, medial-lateral, and vertical directions, as well as an overall composite index following data reduction.⁴⁰

Knee strength was first assessed using an isokinetic dynamometer with concentric testing at 60° per second. Subjects were positioned on the isokinetic dynamometer according to manufacturer specifications. Participants were tested for average peak torque for knee flexion and knee extension. Strength was tested on the injured limb. Subjects performed three practice trials of knee flexion and extension at 50% of their maximum strength, followed by three practice trials at maximum strength. Following one minute of rest, participants proceeded with five consecutive repetitions of flexion and extension at maximum strength. This protocol has been previously described in the literature, and has been shown to have good between-group and side-to-side reliability.^{34,41} Average peak torque for knee flexion and knee extension were calculated and normalized to body mass in kilograms.

A handheld dynamometer was also used to assess isometric knee flexion and extension strength. For knee flexion testing, participants were in the prone position on an exam table with their injured knee in 30-45° of flexion. The subject then accelerated into full flexion strength while the examiner resisted the subject's flexion using a handheld dynamometer placed on the distal one-third of the calf. For knee extension, participants sat on the edge of the exam table with their legs hanging off in 30-45° of flexion. Using a gait belt strap, the dynamometer was secured on the distal one-third of the tibia of the injured leg, participants accelerated into maximum extension. Each trial with the handheld dynamometer was repeated three times. Handheld dynamometry has been previously described and validated for intra-rater, inter-rater, and inter-device reliabil-

ity, especially for proximal muscle testing.⁴²⁻⁴⁴ Peak force was averaged over the three trials and normalized to body mass in kilograms. One tester performed all of the hand-held strength testing. Intra-rater reliability of this tester using the protocol employed in the current study was 0.94 or greater.

Hop distance was assessed for both triple hop and crossover hop. For each hop test, individuals were asked to complete three consecutive hops on the affected foot, jumping as far as possible along a $\frac{3}{4}$ " tape measure on the ground. For the triple hop, all three jumps were made on the same side of a tape measure secured to the floor. For the crossover hop, participants alternated on which side of the tape they jumped with each hop in a lateral-medial-lateral pattern. Trials were discarded if participants landed on the tape or if participants did not stick the landing on their final hop. This procedure has been described previously,^{45,46} with intraclass correlation coefficients of 0.82-0.93.⁴⁷ Participants performed a practice trial for each hop test, and data were recorded for two test trials, with the results averaged and normalized to the participant's height in centimeters.

DATA REDUCTION

Custom MATLAB (Mathworks, v7.0.4, Natick, MA) scripts were used for filtering and processing data for static and dynamic postural stability testing. The data was filtered with a low-pass Butterworth filter using a cutoff frequency of 20 Hz. For static postural stability, the GRF from each of the three successful trials were normalized to body mass in kilograms and averaged. The standard deviation of the GRF in the anterior-posterior, medial-lateral, and vertical directions were calculated, as well as a combined measure from all three directions. For dynamic postural stability, a stability index in the anterior-posterior, medial-lateral, and vertical directions was calculated, in addition to a composite score from all three directions. These values were calculated using the first three seconds after initial contact on the force plate, as determined by the time in which vertical GRF was recorded at greater than five percent of the subject's body mass. The calculations are based on a mean square standardization around a zero point, with lower values for all variables indicating a better score.³⁹

STATISTICAL ANALYSIS

The median ACL-RSI score was calculated across the cohort. Participants were divided into two groups of equal participants based on the median score. Groups were designated as "high score" or "low score" ACL-RSI group, relative to the median.

The data for each variable (height, mass, age, ACL-RSI score, time to RTS, static and dynamic postural stability testing, isokinetic knee flexion/extension, isometric knee flexion/extension, triple/crossover hop) was assessed for normality using a Shapiro-Wilk test. Trial data from the participant's injured limb was assessed. Data from the non-injured limb was not included in this study. An independent samples t-test was used to compare the functional perfor-

mance, strength, and postural stability testing between the high and low score ACL-RSI groups for each variable, and a Mann-Whitney U test was used if the data did not meet normality criteria. All statistical analysis was performed using IBM SPSS Statistics (IBM SPSS, Version 24). Statistical significance was set *a priori* at $p < 0.05$.

RESULTS

The Shapiro-Wilk normality test showed that the data was normally distributed for all variables tested except for age. There was no significant difference in age between the two groups (mean age 18.67 ± 5.17 years and median 17 years in the high-score ACL-RSI group vs. mean age 21.67 ± 7.33 years and median age 18 in the low-score ACL-RSI group, $p=0.331$). The height, body mass, and age demographics between the two groups are presented in [Table 2](#).

The median ACL-RSI score was 74.17. The average ACL-RSI score was 83.1 ± 6.2 for the "high score" group (HS) and 61.8 ± 8.0 for the "low score" group (LS). There was a significant difference in ACL-RSI score between groups (HS= 83.06, LS=61.76, $p<0.001$). The distribution of scores is shown in [Figure 1](#).

The means, standard deviations, and p-values for the HS and LS group for static and dynamic postural stability tasks are presented in [Table 3](#). None of the comparisons between groups achieved statistical significance. The means, standard deviations, and p-values between groups for strength testing are presented in [Table 4](#). High scorers on the ACL-RSI had statistically significant greater isometric knee flexion strength normalized to body mass as measured via handheld dynamometry (36.6 ± 11.4 vs. 32.9 ± 11.8 , $p=0.001$). There were no other statistically significant findings in isometric and isokinetic strength testing. The means, standard deviations, and p-values for hop testing between groups are presented in [Table 5](#). There were no statistically significant differences in performance between the HS and LS groups for hop testing.

DISCUSSION

The purpose of this study was to evaluate if greater psychological readiness for RTS was associated with better performance on strength, postural stability, and hop testing at time of RTS clearance among athletes who had undergone primary ACL reconstruction. It was hypothesized that participants with greater psychological readiness, as determined by ACL-RSI score, would have greater strength, static and dynamic postural stability, and greater hop distance than participants with lower ACL-RSI scores. The hypothesis was partially supported by the finding that participants with greater psychological readiness for RTS had greater mean isometric knee flexor strength. However, no other statistically significant differences were found between groups in any other performance test measured.

Both psychological readiness to RTS and return of knee flexor strength have been shown to be an important predictor of successful RTS outcomes. Athletes with greater ACL-RSI scores, a marker of psychological readiness, are more

Table 2. ACL-RSI Group demographics

	HS Group (n= 9)		LS Group (n = 9)		p-value
	Mean	± SD	Mean	± SD	
Height (cm)	176.43	10.77	169.87	8.66	0.173
Mass (kg)	74.48	11.68	78.80	23.80	0.631
Age (yrs)	18.67	5.17	21.67	7.33	0.331
ACL-RSI Score	83.06	6.22	61.76	8.00	<0.0001*
Mean time to RTS clearance (months)	8.74	1.54	9.50	2.75	0.475

*denotes statistically significant difference

HS= high score ACL-RSI group, LS = low score ACL-RSI group

likely to return to sport after injury recovery.^{13,25} Further, athletes with lower ACL-RSI scores and a smaller improvement in ACL-RSI score throughout postoperative rehabilitation are more likely to experience a second ACL injury upon returning to sport.²¹ Knee flexor strength deficits after ACLR have been associated with an increased second injury risk.^{48,49}

Previous studies have also identified relationships between strength and functional performance testing with psychological readiness to return to sport. Paterno et al identified that athletes with greater fear, a component of psychological readiness, were less likely to return to previous levels of activity and were more likely to have isometric knee extensor strength asymmetry and hop testing asymmetry between legs at time of RTS, and were more likely to experience second ACL injuries.⁵⁰ Lepley et al. observed that lower levels of presurgical pain and greater knee extensor strength in both the injured and uninjured limbs at time of RTS clearance were associated with greater psychological readiness to return to sport.²⁷ Burland et al found that greater isometric and isokinetic extensor strength were as-

sociated with higher ACL-RSI scores at three and six months postoperative in adolescent patients.²⁶ Meierbach et al. and Muller et al. found a positive correlation between ACL-RSI score and triple hop for distance.^{20,28}

The time before recovery of static and postural stability skill after ACLR remains controversial,⁵¹⁻⁵⁴ but has been shown to improve upon training and is often trained in postoperative rehabilitation programs.⁵⁵⁻⁵⁸ Balance deficits may persist six months to three years after ACL injury.⁵⁴ It is possible that no difference was observed between the high and low score groups on static and postural stability testing because all athletes had been exposed to balance testing throughout rehabilitation and had adequately recovered their balance at time of return to sport testing.

There are several limitations to this study. First, there was a relatively small enrollment size. Generalization of these findings should be done with caution, given the small sample size and small age range of athletes enrolled. Participants volunteered to enroll in the study, so enrollment was limited by their willingness to complete testing leading to selection bias. Additionally, the type of surgical graft used intraoperatively, and postoperative rehabilitation programs were not controlled among participants. Athletes may have exhibited reduced hamstring strength if they received a hamstring autograft, which would be unrelated to psychological readiness. Graft type for each participant was not recorded for this study, therefore we were unable to stratify results based on this finding. Postoperative rehabilitation protocols are not standardized after ACLR,^{57,59,60} which could contribute to varying levels of familiarity or preparation for the test battery used in this study. However, because participants were tested after RTS clearance by their clinicians, it is assumed that all subjects had demonstrated some level of competency with strength, balance, and functional performance testing prior to enrollment in this study.

CONCLUSION

This study demonstrated an association between greater isometric knee flexor strength and ACL-RSI score, a surrogate of psychological readiness to RTS, partially supporting the hypothesis. We found no association between greater psychological readiness to RTS and knee extensor strength,

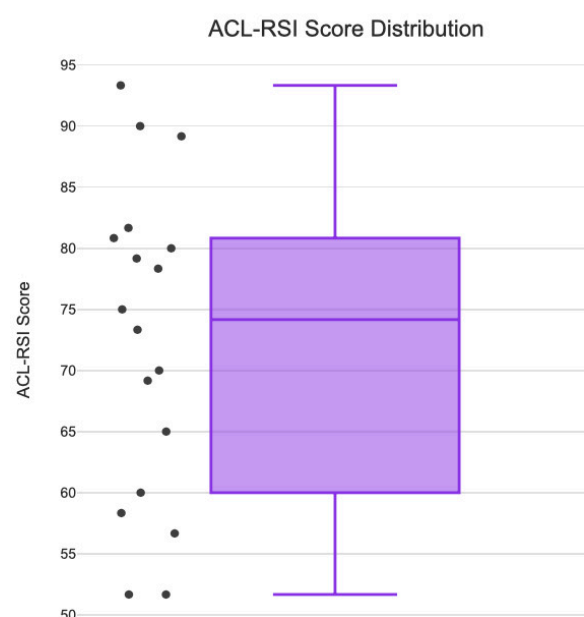


Figure 1. Distribution of ACL-RSI scores.

Table 3. Static and dynamic postural stability testing

	HS Group (n= 9)		LS Group (n = 9)		p-value
	Mean	± SD	Mean	± SD	
Static Balance GRF - AP, EO	2.68	0.73	2.71	1.10	0.947
Static Balance GRF - ML, EO	3.53	1.29	3.53	1.73	0.993
Static Balance GRF - V, EO	5.64	1.68	5.17	2.34	0.630
Static Balance GRF - Combined, EO	7.20	2.15	6.85	3.05	0.780
Static Balance GRF - AP, EC	5.33	1.53	6.29	4.02	0.510
Static Balance GRF - ML, EC	9.09	4.39	10.80	7.02	0.545
Static Balance GRF - V, EC	12.48	5.09	12.85	7.02	0.898
Static Balance GRF - Combined, EC	16.42	6.65	17.99	10.59	0.711
DPSI	0.35	0.05	0.36	0.04	0.479
APSI	0.14	0.01	0.14	0.01	0.303
MLSI	0.03	0.00	0.03	0.01	0.950
VSI	0.32	0.05	0.33	0.04	0.505

GRF= ground reaction forces, EO= eyes open, EC = eyes closed, AP= anterior-posterior, ML= medial-lateral, V= vertical, HS= high score ACL-RSI group, LS = low score ACL-RSI group

Table 4. Strength testing

	HS Group (n= 9)		LS Group (n = 9)		p-value
	Mean	± SD	Mean	± SD	
Isokinetic Knee flexion avg peak torque/ BM *100	124.98%	25.87	102.03%	46.49	0.214
Isokinetic Knee extension avg peak torque / BM * 100	189.06%	45.63	192.68%	67.99	0.896
Handheld dynamometry knee flexion avg peak force/ BM * 100	22.61%	6.01	12.12%	4.88	0.001*
Handheld dynamometry knee extension avg peak force/ BM *100	36.55%	11.37	32.90%	11.82	0.528

*denotes statistical significance

HS= high score ACL-RSI group, LS = low score ACL-RSI group, BM = body mass (kg)

Table 5. Hop testing

	HS Group (n= 9)		LS Group (n = 9)		p-value
	Mean	± SD	Mean	± SD	
Triple hop distance / height	265.19	55.65	209.74	65.66	0.071
Crossover hop distance / height	238.94	54.17	187.58	73.91	0.112

HS= high score ACL-RSI group, LS = low score ACL-RSI group

static or dynamic postural stability, or hop testing among the cohort. Findings from this study indicate that improving hamstring strength may contribute to greater psychological readiness to return to sport, both of which may help reduce second ACL injury rates. Given that psychological readiness has been shown to be related to successful RTS outcomes and lower second injury rates, future research should explore ways to train and optimize psychological readiness in addition to functional strength prior to an athlete's return to sport.

CONFLICTS OF INTEREST AND FINANCIAL DISCLOSURES

None

IRB PROTOCOL

Pro00088033 DUHS IRB

Submitted: August 11, 2021 CST, Accepted: August 16, 2022 CST



This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY-NC-4.0). View this license's legal deed at <https://creativecommons.org/licenses/by-nc/4.0> and legal code at <https://creativecommons.org/licenses/by-nc/4.0/legalcode> for more information.

REFERENCES

1. Sanders TL, Maradit Kremers H, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction: A 21-year population-based study. *Am J Sports Med.* 2016;44(6):1502-1507. doi:[10.1177/0363546516629944](https://doi.org/10.1177/0363546516629944)
2. Mall NA, Chalmers PN, Moric M, et al. Incidence and trends of anterior cruciate ligament reconstruction in the United States. *Am J Sports Med.* 2014;42(10):2363-2370. doi:[10.1177/0363546514542796](https://doi.org/10.1177/0363546514542796)
3. Wiggins ME, Fadale P, Barrach H, Ehrlich M, WW. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Am J Sport Med.* 2016;44(7):1861-1876. doi:[10.1177/0363546515621554](https://doi.org/10.1177/0363546515621554). Risk
4. Lentz TA, Zeppieri G Jr, Tillman SM, et al. Return to preinjury sports participation following anterior cruciate ligament reconstruction: Contributions of demographic, knee impairment, and self-report measures. *J Orthop Sports Phys Ther.* 2012;42(11):893-901. doi:[10.2519/jospt.2012.4077](https://doi.org/10.2519/jospt.2012.4077)
5. Morgan MD, Salmon LJ, Waller A, Roe JP, Pinczewski LA. Fifteen-year survival of endoscopic anterior cruciate ligament reconstruction in patients aged 18 years and younger. *Am J Sports Med.* 2016;44(2):384-392. doi:[10.1177/0363546515623032](https://doi.org/10.1177/0363546515623032)
6. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules reduce reinjury risk after anterior cruciate ligament reconstruction: The Delaware-Oslo ACL cohort study. *Br J Sports Med.* 2016;50(13):804-808. doi:[10.1136/bjports-2016-096031](https://doi.org/10.1136/bjports-2016-096031). SIMPLE
7. Dekker TJ, Godin JA, Dale KM, Garrett WE, Taylor DC, Riboh JC. Return to sport after pediatric anterior cruciate ligament reconstruction and its effect on subsequent anterior cruciate ligament injury. *J Bone Jt Surg - Am Vol.* 2017;99(11):897-904. doi:[10.2106/jbjs.16.00758](https://doi.org/10.2106/jbjs.16.00758)
8. Ross CA, Clifford A, Louw QA. Factors informing fear of reinjury after anterior cruciate ligament reconstruction. *Physiother Theory Pract.* 2017;33(2):103-114. doi:[10.1080/09593985.2016.1271847](https://doi.org/10.1080/09593985.2016.1271847)
9. Failla MJ, Logerstedt DS, Grindem H, et al. Does extended preoperative rehabilitation influence outcomes 2 years after ACL reconstruction? *Am J Sports Med.* 2016;44(10):2608-2614. doi:[10.1177/0363546516652594](https://doi.org/10.1177/0363546516652594)
10. Müller U, Krüger M, Schmidt M, Rosemeyer B. Predictive parameters for return to pre-injury level of sport 6 months following anterior cruciate ligament reconstruction surgery. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(12):3623-3631. doi:[10.1007/s00167-014-3261-5](https://doi.org/10.1007/s00167-014-3261-5)
11. Ardern CL, Kvist J, Webster KE. Psychological aspects of ACL injuries. *Oper Tech Sports Med.* 2015;24(1):77-83. doi:[10.1053/j.otsm.2015.09.006](https://doi.org/10.1053/j.otsm.2015.09.006)
12. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to sport following anterior cruciate ligament reconstruction surgery: A systematic review and meta-analysis of the state of play. *Br J Sports Med.* 2011;45(7):596-606. doi:[10.1136/bjism.2010.076364](https://doi.org/10.1136/bjism.2010.076364)
13. Langford JL, Webster KE, Feller JA. A prospective longitudinal study to assess psychological changes following anterior cruciate ligament reconstruction surgery. *Br J Sport Med.* 2009;43(5):377-381. doi:[10.1136/bjism.2007.044818](https://doi.org/10.1136/bjism.2007.044818)
14. Ardern CL, Österberg A, Tagesson S, Gauffin H, Webster KE, Kvist J. The impact of psychological readiness to return to sport and recreational activities after anterior cruciate ligament reconstruction. *Br J Sports Med.* 2014;48(22):1613-1619. doi:[10.1136/bjsports-2014-093842](https://doi.org/10.1136/bjsports-2014-093842)
15. Nwachukwu BU, Adjei J, Rauck RC, et al. How much do psychological factors affect lack of return to play after anterior cruciate ligament reconstruction? A systematic review. *Orthop J Sport Med.* 2019;7(5):1-7. doi:[10.1177/2325967119845313](https://doi.org/10.1177/2325967119845313)
16. Webster K, Nagelli C, Hewett T, Feller J. Factors associated with psychological readiness to return to sport after an anterior cruciate ligament reconstruction surgery. *Am J Sports Med.* 2019;46(7):1545-1550. doi:[10.1177/0363546518773757](https://doi.org/10.1177/0363546518773757). Factors
17. Ardern CL, Taylor NF, Feller JA, Whitehead TS, Webster KE. Psychological responses matter in returning to preinjury level of sport after anterior cruciate ligament reconstruction surgery. *Am J Sports Med.* 2013;41(7):1549-1558. doi:[10.1177/0363546513489284](https://doi.org/10.1177/0363546513489284)
18. Czuppon S, Racette B, Klein S, Harris-Hayes M. Variables associated with return to sport following anterior cruciate ligament reconstruction: a systematic review. *Br J Sport Med.* 2014;48(5):356-364. doi:[10.1136/bjsports-2012-091786](https://doi.org/10.1136/bjsports-2012-091786). Variables

19. Burgi CR, Peters S, Ardern CL, et al. Which criteria are used to clear patients to return to sport after primary ACL reconstruction? A scoping review. *Br J Sports Med.* 2019;53(18):1154-1161. doi:10.1136/bjsports-2018-099982
20. Müller U, Krüger-Franke M, Schmidt M, Rosemeyer B. Predictive parameters for return to pre-injury level of sport 6 months following anterior cruciate ligament reconstruction surgery. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(12):3623-3631. doi:10.1007/s00167-014-3261-5
21. Mcpherson AL, Feller JA, Hewett TE, Webster KE. Psychological readiness to return to sport is associated with second anterior cruciate ligament injuries. *Am J Sports Med.* 2019;47(4):857-862. doi:10.1177/0363546518825258
22. Mcpherson AL, Feller JA, Hewett TE, Webster KE. Smaller change in psychological readiness to return to sport is associated with second anterior cruciate ligament injury among younger patients. *Am J Sports Med.* 2019;47(5):1209-1215. doi:10.1177/0363546519825499
23. Rosso F, Bonasia DE, Cottino U, Cambursano S, Dettoni F, Rossi R. Factors affecting subjective and objective outcomes and return to play in anterior cruciate ligament reconstruction: A retrospective cohort study. *Joints.* 2018;6(1):23-32. doi:10.1055/s-0038-1636931
24. Webster KE, Feller JA, Lambros C. Development and preliminary validation of a scale to measure the psychological impact of returning to sport following anterior cruciate ligament reconstruction surgery. *Phys Ther Sport.* 2008;9(1):9-15. doi:10.1016/j.ptsp.2007.09.003
25. Sadeqi M, Klouche S, Bohu Y, Herman S, Lefevre N, Gerometta A. Progression of the psychological ACL-RSI score and return to sport after anterior cruciate ligament reconstruction. *Orthop Journal Sport Med.* 2018;6(12):1-7. doi:10.1177/2325967118812819
26. Burland JP, Kostyun RO, Kostyun KJ, Solomito M, Nissen C, Milewski MD. Clinical outcome measures and return-to-sport timing in adolescent athletes after anterior cruciate ligament reconstruction. *J Athl Train.* 2018;53(5):442-451. doi:10.4085/1062-6050-302-16
27. Lepley AS, Pietrosimone B, Cormier ML. Quadriceps function, knee pain, and self-reported outcomes in patients with anterior cruciate ligament reconstruction. *J Athl Train.* 2018;53(4):337-346. doi:10.4085/1062-6050-245-16
28. Meierbachtol A, Yungtum W, Paur E, Bottoms J, Chmielewski TL. Psychological and functional readiness for sport following advanced group training in patients with anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther.* 2018;48(11):864-872. doi:10.2519/jospt.2018.8041
29. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res.* 1985;198:42-49. doi:10.1097/00003086-198509000-00007
30. Briggs KK, Steadman JR, Hay CJ, Hines SL. Lysholm score and tegner activity level in individuals with normal knees. *Am J Sports Med.* 2009;37(5):898-901. doi:10.1177/0363546508330149
31. Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM. Measures of knee function: international knee documentation committee (IKDC) subjective knee evaluation form. *Arthritis Care Res.* 2011;63(011):208-228. doi:10.1002/acr.20632.Measures
32. Goldie PA, Evans OM, Bach TM. Steadiness in one-legged stance: development of a reliable force-platform testing procedure. *Arch Phys Med Rehabil.* 1992;73(4):348-354. doi:10.1016/0003-9993(92)90008-k
33. Goldie PA, Bach TM, Evans OM. Force platform measures for evaluating postural control: reliability and validity. *Arch Phys Med Rehabil.* 1989;70(7):510-517.
34. Abt JP, Sell TC, Laudner KG, et al. Neuromuscular and biomechanical characteristics do not vary across the menstrual cycle. *Knee Surg Sports Traumatol Arthrosc.* 2007;15(7):901-907. doi:10.1007/s00167-007-0302-3
35. Sell TC, Lovalekar MT, Nagai T, Wirt MD, Abt JP, Lephart SM. Gender differences in static and dynamic postural stability of soldiers in the Army's 101st airborne division (air assault). *J Sport Rehabil.* 2018;27(2):126-131. doi:10.1123/jsr.2016-0131
36. Sell T, House A, Abt J, Lephart S. An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults. *Phys Ther Sport.* 2012;13(2):80-86. doi:10.1016/j.ptsp.2011.06.006
37. Akins JS, Longo PF, Bertoni M, et al. Postural stability and isokinetic strength do not predict knee valgus angle during single-leg drop-landing or single-leg squat in elite male rugby union players. *Isokinet Exerc Sci.* 2013;21(1):37-46. doi:10.3233/ies-2012-0469

38. Ross S, Guskiewicz K. Time to Stabilization: A Method for Analyzing Dynamic Postural Stability. *Int J Athl Ther Train*. 2003;8(3):37-39.
39. Sell TC, Pederson JJ, Abt JP, et al. The addition of body armor diminishes dynamic postural stability in military soldiers. *Mil Med*. 2013;178(1):76-81. doi:10.7205/milmed-d-12-00185
40. Wikstrom EA, Tillman MD, Smith AN, Borsa PA. A new force-plate technology measure of dynamic postural stability: The dynamic postural stability index. *J Athl Train*. 2005;40(4):305-309.
41. Sell TC, Clark NC, Abt JP, Lovalekar M, Lephart SM. Isokinetic strength of fully operational U.S. Navy Seals with a previous history of shoulder and knee injury. *Isokinet Exerc Sci*. 2016;24(4):349-356. doi:10.3233/ies-160637
42. Jackson SM, Cheng MS, Smith AR Jr, Kolber MJ. Intrarater reliability of hand held dynamometry in measuring lower extremity isometric strength using a portable stabilization device. *Musculoskelet Sci Pract*. 2017;27:137-141. doi:10.1016/j.math.2016.07.010
43. Mentiplay BF, Perraton LG, Bower KJ, et al. Assessment of lower limb muscle strength and power using hand-held and fixed dynamometry: A reliability and validity study. *PLoS One*. 2015;10(10):1-19. doi:10.1371/journal.pone.0140822
44. Hébert LJ, Maltais DB, Lepage C, Saulnier J, Crête M, Perron M. Isometric muscle strength in youth assessed by hand-held dynamometry: A feasibility, reliability, and validity study: A feasibility, reliability, and validity study. *Pediatr Phys Ther*. 2011;23(3):289-299. doi:10.1097/pep.0b013e318227cfff
45. Noyes FR, Butler DL, Grood ES, Zernicke RF, Hefzy MS. Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. *J Bone Jt Surg*. 1984;66-A(3):344-352. doi:10.2106/00004623-198466030-00005
46. Haitz K, Shultz R, Hodgins M, Matheson GO. Test-retest and interrater reliability of the functional lower extremity evaluation. *J Orthop Sports Phys Ther*. 2014;44(12):947-954. doi:10.2519/jospt.2014.4809
47. Reid A, Birmingham TB, Stratford PW, Alcock GK, Giffin JR. Hop testing provides a reliable and valid outcome measure during rehabilitation after anterior cruciate ligament reconstruction. *Phys Ther*. 2007;87(3):337-349. doi:10.2522/ptj.20060143
48. Griffin LY, Albohm MJ, Arendt EA, et al. Understanding and preventing noncontact anterior cruciate ligament injuries: A review of the Hunt Valley II Meeting, January 2005. *Am J Sports Med*. 2006;34(9):1512-1532. doi:10.1177/0363546506286866
49. Kellis E, Galanis N, Kofotolis N. Hamstring-to-quadriceps ratio in female athletes with a previous hamstring injury, anterior cruciate ligament reconstruction, and controls. *Sports*. 2019;7(10):214. doi:10.3390/sports7100214
50. Paterno MV, Flynn K, Thomas S, Schmitt LC. Self-reported fear predicts functional performance and second ACL injury after ACL reconstruction and return to sport: a pilot study. *Sports Health*. 2018;10(3):228-233. doi:10.1177/1941738117745806
51. Ferdowsi F, Rezaeian ZS. Evaluating equilibrium in anterior cruciate ligament reconstruction. *J Phys Ther Sci*. 2018;30(5):726-729. doi:10.1589/jpts.30.726
52. Fischer-Rasmussen T, Jensen PE. Proprioceptive sensitivity and performance in anterior cruciate ligament-deficient knee joints. *Scand J Med Sci Sport*. 2000;10(2):85-89. doi:10.1034/j.1600-0838.2000.010002085.x
53. Clagg S, Paterno MV, Hewett TE, Schmitt LC. Performance on the modified star excursion balance test at the time of return to sport following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2015;45(6):444-452. doi:10.2519/jospt.2015.5040
54. Delahunt E, Chawke M, Kelleher J, et al. Lower limb kinematics and dynamic postural stability in anterior cruciate ligament-reconstructed female athletes. *J Athl Train*. 2013;48(2):172-185. doi:10.4085/1062-6050-48.2.05
55. Taubert M, Mehnert J, Pleger B, Villringer A. Rapid and specific gray matter changes in M1 induced by balance training. *Neuroimage*. 2016;133:399-407. doi:10.1016/j.neuroimage.2016.03.017
56. Garrison JC, Bothwell JM, Wolf G, Aryal S, Thigpen CA. Y Balance Test™ anterior reach symmetry at three months is related to single leg functional performance at time of return to sports following anterior cruciate ligament reconstruction. *Int J Sports Phys Ther*. 2015;10(5):602-611.
57. Saka T. Principles of postoperative anterior cruciate ligament rehabilitation. *World J Orthop*. 2014;5(4):450-459. doi:10.5312/wjo.v5.i4.450

58. Cavanaugh JT, Powers M. ACL Rehabilitation progression: where are we now? *Curr Rev Musculoskelet Med.* 2017;10(3):289-296. doi:10.1007/s12178-017-9426-3

59. Simoneau GG, Wilk KE. The challenge of return to sports for patients post-ACL reconstruction. *J Orthop Sports Phys Ther.* 2012;42(4):300-301. doi:10.2519/jospt.2012.0106

60. Wright R, Preston E, Fleming B, et al. A systematic review of anterior cruciate ligament reconstruction rehabilitation part II: open versus closed kinetic chain exercises, neuromuscular electrical stimulation, accelerated rehabilitation, and miscellaneous topics. *J Knee Surg.* 2008;21(3):225-234. doi:10.1055/s-0030-1247823